


Northward expansion of the Critically Endangered Arabian leopard in Dhofar, Oman

HADI AL HIKMANI^{*1,2,3}  and KHALID AL HIKMANI^{1,2,4}

Abstract The Critically Endangered Arabian leopard *Panthera pardus nimr* was believed to be absent from the Nejd region in Dhofar Governorate, Oman. However, a scat confirmed by DNA analysis in 2011 and camera-trap images from 2014 confirmed the presence of the leopard in this region. During 2014–2021, our camera traps documented at least eight individual leopards, demonstrating the species is resident and breeding in the region. This finding extends the Arabian leopard's known range in Oman by c. 40 km northwards. To improve detection probability, we recommend that camera-trap surveys for the leopard in the Arabian Peninsula are of at least 18 weeks duration. We advocate the designation of central and western areas of the Nejd as a National Nature Reserve, to protect critical habitat for the Arabian leopard and for other species in this region.

Keywords Arabian leopard, Arabian Peninsula, camera trap, Dhofar mountains, Nejd, Oman, *Panthera pardus nimr*

The Arabian leopard *Panthera pardus nimr* is the largest extant felid species in the Arabian Peninsula and currently occupies just 2% of its historical range (Jacobson et al., 2016; Dunford et al., 2023; Al Hikmani et al., 2024b). Arabian leopards face multiple threats, including persecution by people, habitat loss and fragmentation, prey scarcity, capture for the illegal pet trade, and genetic depletion as a result of the small population size (Al Jumaily et al., 2006; Spalton et al., 2006; Al Johany, 2007; Al Hikmani, 2018; Islam et al., 2018). The global wild population is estimated to comprise 100–120 individuals, with the largest known subpopulation in the Dhofar Governorate of southern Oman (Al Hikmani et al., 2024a, 2024b).

In Dhofar, the leopard was once widespread throughout the mountainous areas, including the northward draining wadis of the Nejd region (Spalton & Al Hikmani, 2014). The Nejd, north of the Dhofar mountains (Fig. 1), is characterized by a heterogeneous landscape of rolling plateaus, low cliffs and wadis that extend northward to the Empty Quarter

sand desert. Prominent wadis in this area include Aydam and Nakhur in the west, Marweet, Gharah, Amat and Ghadun in the central area, and Andhur and Arah in the east. The Nejd is arid, receiving < 100 mm of rainfall per year (Al Kindi et al., 2023), with sparse vegetation dominated by thorn trees such as *Vachellia* spp. Annual temperature is 10–28 °C in the winter (December–March) and 35–45 °C in the summer (April–August). There are only a few villages along the southern and northern fringes of the Nejd, and the Jabal Samhan Nature Reserve occupies the easternmost area.

Anecdotal local reports of killing of leopards suggested that the Arabian leopard may have been extirpated from the Nejd, with any remaining individuals having been pushed towards the southern slopes of the Dhofar mountains (Fig. 1). Camera-trap surveys in the central Nejd between 20 September 2004 and 17 June 2007, and in the western Nejd between 5 September and 30 December 2013 did not detect leopards, leading to presumption of their absence (Office for Conservation of the Environment, unpubl. data; Table 1, Fig. 2a,b). Surveys during 2008–2011 reported scats and scrape marks in central Nejd but camera-trap deployments did not record leopards (Mazzolli & Hammer, 2008; Mazzolli, 2009; McGregor et al., 2011). However, DNA analysis of a single scat found in 2011 confirmed it to be that of a leopard (Mazzolli et al., 2013, 2017), and in 2014 camera-trap images confirmed the presence of leopards in the central Nejd (M1 and F1; Table 1, Fig. 2a; Al Hikmani et al., 2015). These findings prompted further surveys to determine whether leopards are resident in the area, or if their presence was a temporary expansion resulting from individuals dispersing from known populations in the south.

During 2015–2019, we conducted four unstructured camera-trap surveys in the central Nejd (Table 1, Fig. 2a). On 20 February 2015, a female leopard (F1) previously recorded in January 2014 in Wadi Amat (central Nejd) was photographed again. This female was also recorded on 20 March 2015, 25 March 2015 (with a 2–3 month-old cub) and 11 July 2015. The same female, now with an adult cub, was recorded further east in Wadi Ghadun in January 2017 (Plate 1). Another female (F2) was documented in the upper reaches of central Nejd in October 2017. A male leopard (M2) was recorded in Wadi Marweet in April 2017, and a different male (M3) in Wadi Ghadun in August 2019. Genetic analysis of scats collected during 2014–2017 identified three individual leopards in Wadi Amat (Al Hikmani et al., 2024b).

During 7 January–8 December 2021, we conducted three systematic camera-trapping surveys in the Nejd to assess

*Corresponding author, h.alhakmani@rcu.gov.sa

¹Office for Conservation of the Environment, Diwan of Royal Court, Muscat, Oman

²Royal Commission for AlUla, AlUla, Saudi Arabia

³IUCN Species Survival Commission Cat Specialist Group

⁴General Directorate of Environment, Environment Authority, Salalah, Oman

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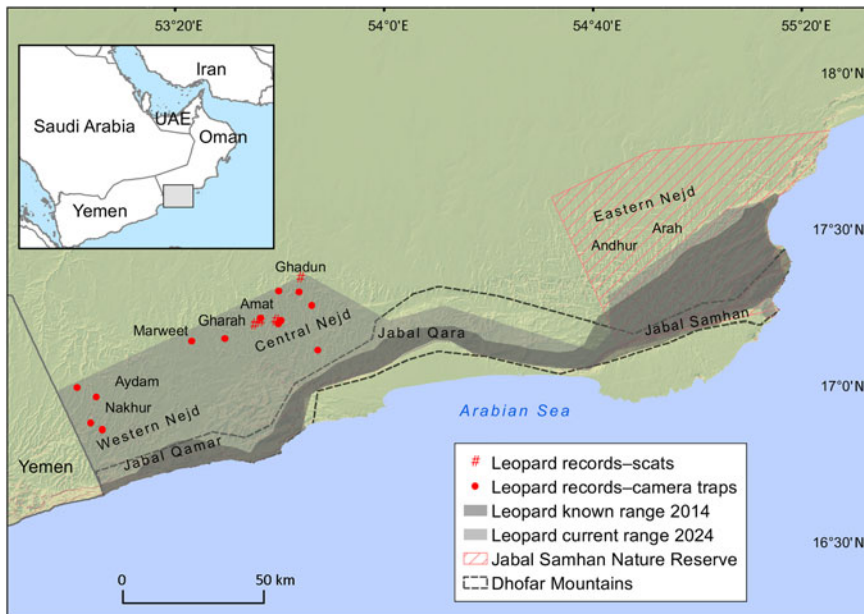


FIG. 1 Dhofar Governorate, Oman, showing the Nejd region and the location of Arabian leopard *Panthera pardus nimr* records in western and central Nejd. The leopard's known range in 2014 is from Spalton & Al Hikmani (2014), and the current range in 2024 is based on the IUCN Red List (Al Hikmani et al., 2024a) and this study.

TABLE 1 Camera-trap surveys for the Arabian leopard *Panthera pardus nimr* in the central, western and eastern Nejd during 2004–2021, with survey periods, number of camera traps used, leopard records in chronological order (Fig. 2), effort and number of individual leopards identified.

| Camera-trap survey (area) | Survey period | Number of camera traps | Leopard records | Effort (trap-days) | Number of individuals (ID) ¹ | Source |
|---------------------------|-----------------------|------------------------|-----------------|--------------------|---|--|
| 2004–2007 (Central) | 20/09/2004–17/06/2007 | 8 | | 7,222 | 0 | Office for Conservation of the Environment (unpubl. data) |
| 2008–2011 (Central) | 03/02/2008–24/06/2008 | 5 | | 712 | 0 | Mazzolli & Hammer (2008), McGregor et al. (2011), Mazzolli et al. (2013) |
| | 17/01/2010–12/02/2010 | 7 | | 135 | 0 | |
| | 08/02/2011–02/03/2011 | 14 | | 143 | 0 | |
| 2013 (Western) | 05/09/2013–30/12/2013 | 5 | | 464 | 0 | Office for Conservation of the Environment (unpubl. data) |
| 2014 (Central) | 31/12/2013–18/06/2014 | 5 | 1,2,3 | 170 | 2 (M1,F1) | Al Hikmani et al. (2015) |
| 2015–2019 (Central) | 11/01/2015–22/09/2015 | 5 | 4,5,6,7 | 1,230 | 2 (F1,cub) | Office for Conservation of the Environment (unpubl. data) |
| | 28/09/2016–04/06/2017 | 8 | 8,9 | 1,967 | 3 (F1,cub,M2) | |
| | 18/09/2017–21/12/2017 | 7 | 10 | 649 | 1 (F2) | |
| | 17/06/2019–20/10/2019 | 5 | 11 | 618 | 1 (M3) | |
| 2021 (Western) | 07/01/2021–18/05/2021 | 20 | 12,13,14,15,17 | 2231 | 2 (M4,F3) | This study |
| 2021 (Central) | 10/10/2021–08/12/2021 | 20 | 16,18 | 1154 | 1 (M5) | This study |
| 2021 (Eastern) | 17/01/2021–25/05/2021 | 34 | | 2,283 | 0 | This study |

¹M, male; F, female.

leopard status and distribution: western Nejd (239 km²) north of Jabal Qamar, central Nejd (203 km²) north of Jabal Qara, and eastern Nejd (425 km²) north of Jabal Samhan (Table 1; Fig. 2a–c). Cameras were spaced 2–4 km apart and operated continuously with a 1 s delay between consecutive photos.

Across 5,668 trap-days, we recorded the leopard and 12 additional species of wild mammals > 1 kg (Table 2). We obtained four independent records of two individual leopards, a male (M4) and a female (F3), in the western Nejd north of Jabal Qamar, close to the border with Yemen, on 13 January, 22 February, 22 March and 13 May

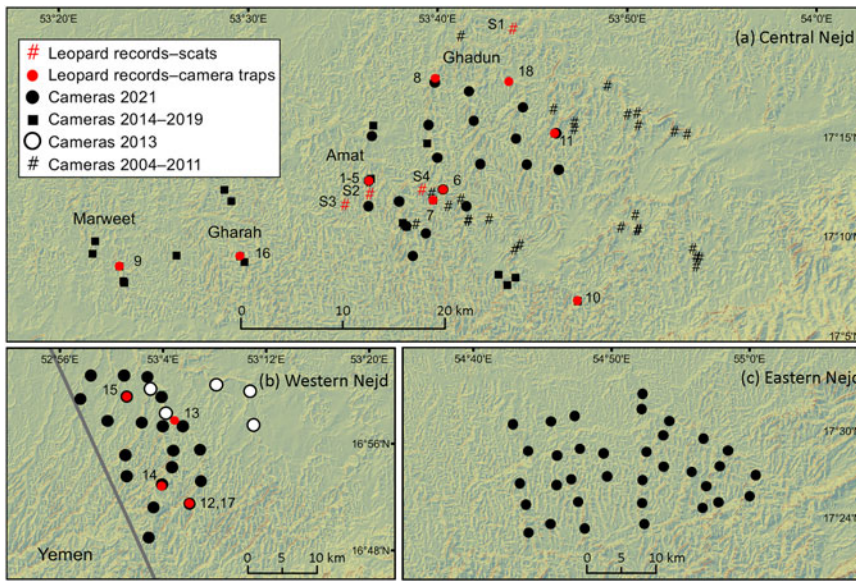


FIG. 2 Detailed locations of camera traps deployed in the (a) central, (b) western and (c) eastern Nejd region (Fig. 1) during 2014–2021. Numbers (Table 1) indicate records of the Arabian leopard, in chronological order (1, 1 January 2014; 2, 21 January 2014; 3, 9 May 2014; 4, 20 February 2015; 5, 20 March 2015; 6, 25 March 2015; 7, 11 July 2015; 8, 25 January 2017; 9, 12 April 2017; 10, 20 October 2017; 11, 19 August 2019; 12, 13 January 2021; 13, 22 February 2021; 14, 22 March 2021; 15, 13 May 2021; 16, 20 May 2021; 17, 15 August 2021; 18, 22 November 2021). S1 indicates the leopard scat from 2011 (Mazzolli et al., 2017), and S2–S4 are the leopard scats from the 2014–2017 genetic study (Al Hikmani et al., 2024b).

2021. We recorded one male leopard (M5) from the central Nejd, on 22 November 2021, but no leopards from the eastern Nejd, despite its proximity to a known leopard population in southern Jabal Samhan, and the absence of geographical barriers to leopard movement (Spalton et al., 2006; Al Hikmani et al., 2024b). Two independent leopard records from the central (20 May 2021) and western Nejd (15 August 2021) were obtained from opportunistic camera traps deployed by wildlife rangers. In total, we recorded 18 independent camera-trap detections of at least eight individual leopards and a cub during 2014–2021, providing unequivocal evidence that the Arabian leopard is not only resident but also breeding in the central and western Nejd.

These records confirm the return of leopards to the central Nejd, indicate its presence in the western Nejd for

the first time, and extend the species' known range in Dhofar northward by c. 40 km, with the northernmost confirmed record in Dhofar to date. Further northwards, the habitat becomes open and with sparse cover, limiting opportunities for further range expansion.

Given the absence of evidence of leopards in the central Nejd during 2004–2007 despite camera-trap surveys, it is likely that leopards were absent during this period. The leopard records from camera traps placed in the same location in 2014, combined with evidence from 2011 surveys (Mazzolli & Hammer, 2008; Mazzolli, 2009; McGregor et al., 2011), provide further evidence of the apparent return of leopards to the central Nejd.

We recommend long-term monitoring of leopard populations in the central and western Nejd, and repeating surveys in the eastern Nejd, north of Jabal Samhan. The eastern Nejd is the larger of the three areas, and more camera traps were deployed there than in the central or western Nejd, but the number of effective trapping days (67 days) was lower than in western Nejd (111 days), where we recorded two leopards. Our survey in the eastern Nejd may also have been compromised by the activity of frankincense *Boswellia sacra* resin harvesters, recorded at 20 of our 34 camera deployment sites, which could have resulted in leopards avoiding this area at the time. The extent of favourable leopard habitat and the abundance of prey species in the eastern Nejd makes further surveys a priority in this area.

Based on our leopard detections in the western Nejd, we recommend a minimum camera-trap deployment period of 18 weeks, to achieve a 95% probability of recording the presence of Arabian leopards in this region (Fig. 3). This recommendation has implications for surveying and monitoring Arabian leopards and other threatened arid-adapted mammal species across the Arabian Peninsula. In addition, and given



PLATE 1 Female F1 (record number 8; Fig. 2), with an adult cub, recorded in Wadi Ghadun in the Central Nejd on 25 January 2017.

TABLE 2 Mammal species recorded during the 2021 camera-trap surveys in the Nejd region, with their IUCN Red List category and the areas in which they were recorded.

| Species | Red List category | Recorded areas |
|--|-----------------------|---------------------|
| Arabian leopard | Critically Endangered | West, Central |
| Caracal <i>Caracal caracal schmitzi</i> | Least Concern | Central |
| African wildcat <i>Felis lybica lybica</i> | Least Concern | West, Central, East |
| Striped hyaena <i>Hyaena hyaena sultana</i> | Near Threatened | West, Central |
| Arabian wolf <i>Canis lupus arabs</i> | Least Concern | West, Central, East |
| Blanford's fox <i>Vulpes cana</i> | Least Concern | Central, East |
| Arabian red fox <i>Vulpes vulpes arabica</i> | Least Concern | West, Central, East |
| Honey badger <i>Mellivora capensis</i> | Least Concern | West, Central |
| Indian crested porcupine <i>Hystrix indica</i> | Least Concern | West, Central, East |
| Nubian ibex <i>Capra nubiana</i> | Vulnerable | West, Central, East |
| Arabian gazelle <i>Gazella arabica</i> | Vulnerable | West, Central, East |
| Cape hare <i>Lepus capensis</i> | Least Concern | East |
| Rock hyrax <i>Procavia capensis</i> | Least Concern | West, Central, East |

the conservation importance of the Arabian leopard, we recommend designating the central and western Nejd as a National Nature Reserve, to protect critical habitat. Such a designation would also benefit other charismatic fauna (e.g. the Nubian ibex *Capra nubiana* and Arabian gazelle *Gazella arabica*) and flora such as frankincense and myrrh

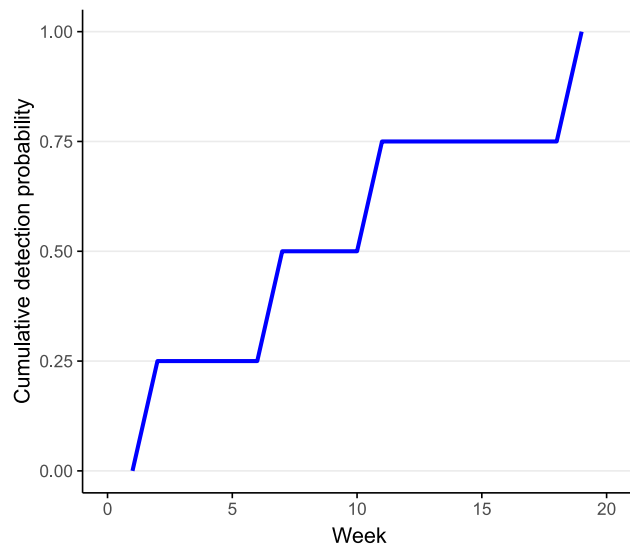


FIG. 3 Cumulative probability of camera-trap detection of the Arabian leopard in the western Nejd.

Commiphora myrrha, both of which are of regional and global interest.

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Conflicts of interest None.

Ethical standards This research abided by the Oryx guidelines on ethical standards.

Data availability Data are available from the authors upon reasonable request.

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